



## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification<sup>6</sup>:H01S 3/19, 3/025, H01L 27/15, 21/22,  
33/00, 21/266

A1

(11) International Publication Number:

WO 96/27226

(43) International Publication Date:

6 September 1996 (06.09.96)

(21) International Application Number: PCT/CA96/00121

(22) International Filing Date: 28 February 1996 (28.02.96)

(30) Priority Data:

9503981.4

28 February 1995 (28.02.95)

GB

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DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

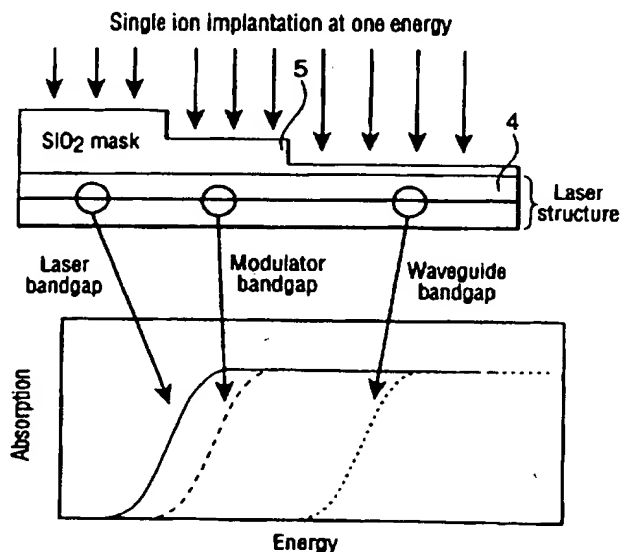
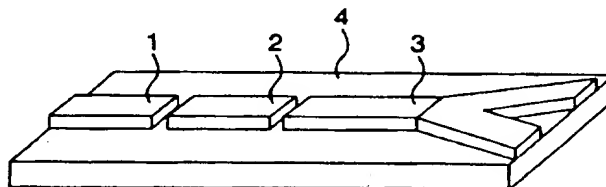
Published

With international search report.

(54) Title: BANDGAP TUNING OF SEMICONDUCTOR WELL STRUCTURE

## (57) Abstract

In a method of bandgap tuning of a quantum well heterostructure wherein ions are implanted in the heterostructure by ion implantation, the ions are implanted so that different regions are implanted in such a way as to create different concentrations of defects. This provides varying bandgap energies to various areas of the heterostructure during a subsequent thermal treatment, which removes residual defects and initiates intermixing in the quantum well region to result in a structure having a selectively shifted bandgap.



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## BANDGAP TUNING OF SEMICONDUCTOR WELL STRUCTURE

This invention relates to semiconductor heterostructures and, more specifically, to a method of bandgap tuning a quantum well structure in a spatially selective manner.

The invention can also be applied to post processing to modify device properties. The invention provides a useful and new method for the monolithic integration of multi-use devices on a single substrate with simplified growth topology.

Optical and electrical properties of quantum well structures are of great importance for novel semiconductor device applications. The ultimate goal of monolithic integration of optical, optoelectronic and electronic components requires the capability for controllable lateral and vertical modifications of optical constants and electrical characteristics in such components.

Present techniques include etching and regrowth. Regrowth involves growing a device structure such as a laser, and then etching away the regions where other components, such as modulators etc., are desired and regrowing these components. This involves a large number of processing steps, with problems associated with growing good quality material after etching, leading to poor device yields.

US patent no. 5,238,868 describes in detail a technique for shifting the bandgap using quantum well intermixing. This technique involves mixing quantum well material with surrounding barrier material to change the bandgap of the quantum well. This is performed by introducing impurities or defects into the quantum well in the region of the wafer that requires a modification

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mask, the degree of damage can be controlled. The mask may be removed prior to thermal treatment, although this is not necessary.

In another embodiment, the ions are implanted  
5 through a mask of varying density to achieve a similar result. In other embodiments, alternative techniques are employed to vary the dosage in a spatially selective manner.

The inventive technique works because of dependence  
10 of the shift in quantum well bandgap on defect concentration, which in turn is dependent on ion energy and/or dosage. The greater the dose, or the higher the energy of the implanted ions, the more damage that will be done. This invention provides the enabling technology  
15 for the integration and modification of optoelectronic components on a monolithic structure.

The invention also provides an apparatus for bandgap tuning a quantum well heterostructure comprising means for implanting ions in said heterostructure to create  
20 defects therein, and means for thermally treating heterostructure to initiate intermixing in the quantum well region, characterized in that it further comprises means for controlling the ion implantation in a spatially selective manner so as that different regions of said  
25 heterostructure have different concentrations of defects, which during the subsequent thermal treatment give rise to different bandgap shifts.

In a preferred embodiment, the invention also includes means for providing a mask of varying thickness  
30 or density on the surface of said heterostructure so that different regions are implanted with ions having different energies during a single ion implantation, thereby providing varying bandgap energies to various

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Figure 8b shows an embodiment employing a multiple thickness contact mask created using a shadow masking technique;

Figure 9a shows multiple ion implants using contact masks; and

Figure 9b shows multiple ion implants using shadow masks.

Figure 1 shows the change in quantum well bandgap with ion implantation energy for an InP based quantum well laser. This has been implanted with different energy P ions at a dose of  $2.5 \times 10^{13} \text{ cm}^{-2}$ , and then annealed at  $700^\circ\text{C}$  for 60 seconds. As can be seen from Figure 1, there is a strong dependence of bandgap shift on ion energy up to 2 MeV. By implanting, for example, 2 MeV ions through a  $\text{SiO}_2$  mask using standard technology compatible with InP processing, any bandgap shift from 0 to 41 meV can be obtained with a single ion implant. This can be performed purely by varying the mask thickness, although other means to vary the implanted dose can be employed.

Figure 2(a) shows a typical photonic circuit that can be created using the above technique. It consists of a laser 1, a modulator 2, which controls the output of the laser 1, and a waveguide 3 to send the light to another region of the wafer 4, or an optical fiber.

By using an  $\text{SiO}_2$  mask of varying thickness, as shown in Figure 2(b), different defect concentrations are created in different regions of the wafer using a single ion implantation step. As ions travel through the  $\text{SiO}_2$  they are slowed down, i.e. they decrease in energy. The thicker the  $\text{SiO}_2$ , the more the ions are slowed, until they are stopped completely. The mask is implanted with ions of a single energy, e.g. 1 MeV, but the surface of the wafer actually receives ions with different energies, 0

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The addition of a high reflecting coating on the Facet 1 (Figure 3(a)) and anti-reflection coating on Facet 2 (Figure 3a) results in a uni-directional extended spectrum SLD. Mirrors on both facets result in an extended-gain-spectrum laser. With anti-reflection coatings on both facets, an amplifier can be made with an extended wavelength gain.

It is also possible to practice the invention using multiple masks and multiple implants. In such an embodiment, for example, each density region can be exposed for a desired length of time through a mask having an aperture over the associated region where implantation was desired. Different masks can be exposed for a desired length of time through a mask having other regions, which can be exposed for a different length of time so as to vary the density of ion implantation between regions. Alternatively, the apertures in the successive masks could overlap so that the regions of higher desired density received higher doses.

In a further embodiment, instead of varying the thickness of the mask, it is possible to vary the density. This can be achieved, for example, by depositing an  $\text{SiO}_2$  mask on some regions of the surface of the heterostructure and then sputtering metal on other regions where it is desired to have a higher density mask.

In Figure 4, a monolithic demultiplexer comprises a substrate 30 and an InP based laser structure 31. Photodetectors 32, 33 are formed over different regions of the structure, which has been subjected to bandgap tuning in accordance with the invention. In the structure of Figure 4, four different thicknesses (0, 0.65, 1.2 and 2.2 $\mu\text{m}$ ) of  $\text{SiO}_2$  mask were evaporated onto the sample

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beam current, or by repetitive patterning, the number of defects can be adjusted in a lateral manner on the wafer. In step 1, the left side of the wafer is subjected to a large ion dose, and in step 2, the right side is  
5 subjected to a small ion dose.

After a repetitive scan in step 3, the wafer is subjected to a single rapid thermal anneal (RTA) in step 4 to effect a bandgap shift that depends on the concentration of defects, and thus the ion dose in the  
10 various regions. The Quantum well bandgap shifts reflect the defect density produced by the complex ion implantation pattern written on the wafer.

Figure 7 shows in detail a method of making a wafer employing a single, multiple thickness mask. After  
15 despositing an  $\text{SiO}_2$  layer 11 on wafer surface 1 (step 1), a temporary mask 12 is applied to cover a portion of the wafer surface, and a deep etch (step 3) is performed on the remainder. The temporary mask 12 is removed and a second  $\text{SiO}_2$  deposition 13 performed. The process is  
20 repeated through steps 6 to 12 adding additional  $\text{SiO}_2$  layers 15 and employing masks 14, 16 to produce a multiple thickness mask as shown at step 12. Finally, in step 13, the wafer is subjected to ion implantation. Clearly, the exposed region receives the greatest ion  
25 dose and thus exhibits the greatest band gap shift.

Figure 8a shows the use of a single multiple thickenss contact mask. As in Figure 7, an  $\text{SiO}_2$  mask 11 is formed on the surface of the wafer 10. A temporary mask 12 applied to cover parts of the exposed surface. A deep  
30 etch (step 3) is then performed and the temporary mask 12 removed. A second temporary mask 14 is applied and a shallow etch performed, which after removal of the mask 14, produces the stepped structure shown in step 7.

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anneal, after all the doses have been applied, or  
separate anneals after each dose.

The described technique allows the monolithic  
integration of multi-use devices on a single substrate  
5 without deterioration of the material quality after the  
process.

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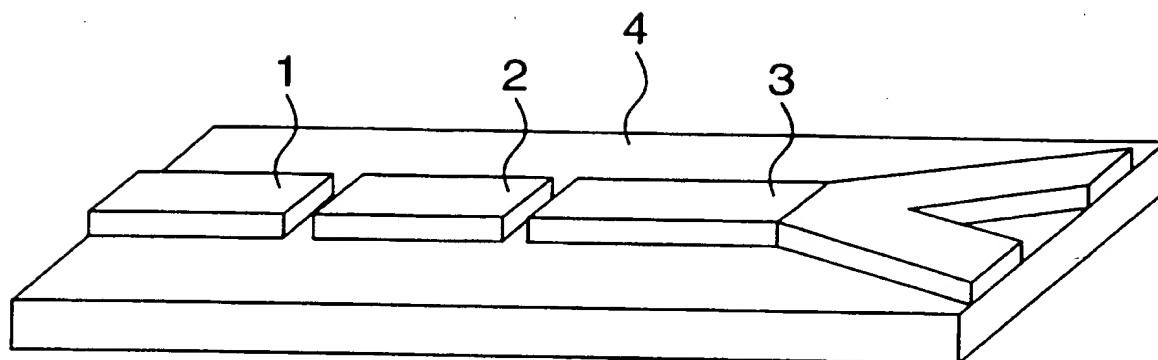
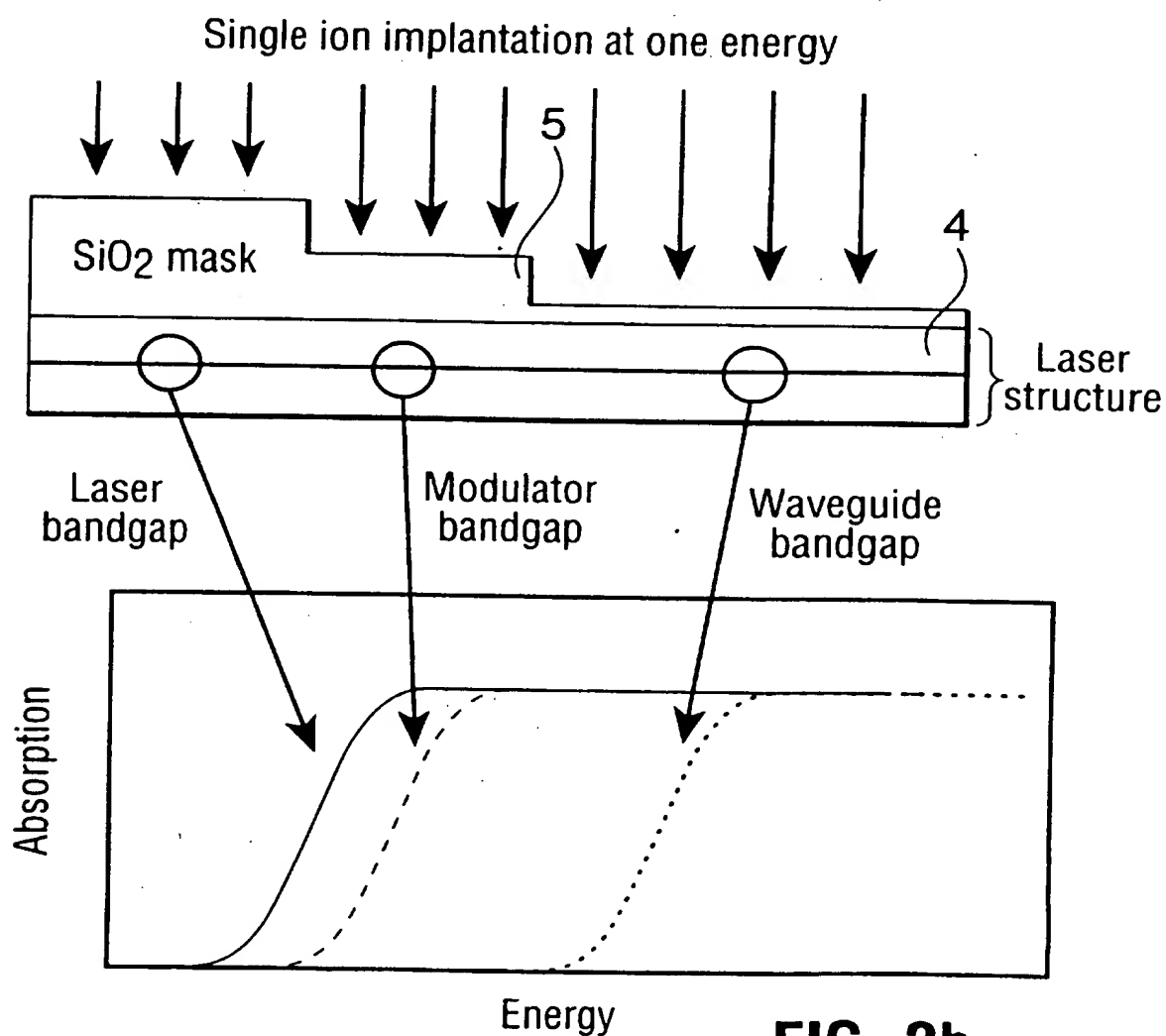
8. A method as claimed in claim 2 or 3, characterized in that the mask is an SiO<sub>2</sub> mask.
9. A method as claimed in claim 2 or 3, characterized in that the heterostructure is an InP-based quantum well  
5 laser.
10. A method as claimed in claim 2 or 3, characterized in that the heterostructure is a super-luminescent diode.
11. A method as claimed in claim 2 or 3, characterized in that the heterostructure is a demultiplexer for  
10 wavelength division multiplexing.
12. A method as claimed in claim 2 or 3, characterized in that the heterostructure is an integrated internal laser modulator.
13. A method as claimed in claim 2 or 3, characterized in that the heterostructure is a single mode waveguide  
15 laser.
14. A method as claimed in claim 2 or 3, characterized in that the heterostructure is a transparent facet for a high-powered laser.
- 20 15. A method as claimed in claim 2 or 3, characterized in that the heterostructure is annealed at about 700° for about 60 seconds.
16. An apparatus for bandgap tuning a quantum well heterostructure comprising means for implanting ions in  
25 said heterostructure to create defects therein, and means for thermally treating heterostructure to initiate intermixing in the quantum well region, characterized in that it further comprises means for controlling the ion implantation in a spatially selective manner so as that  
30 different regions have of said heterostructure have different concentrations of defects, which during the



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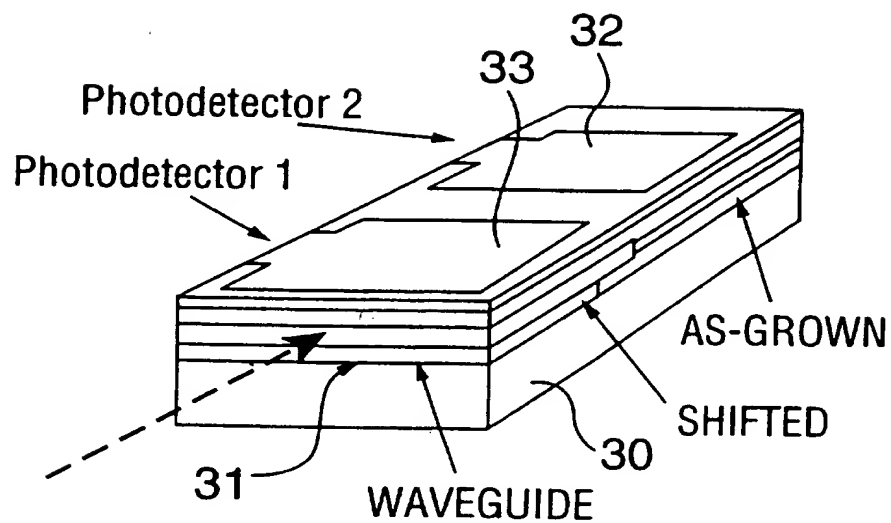
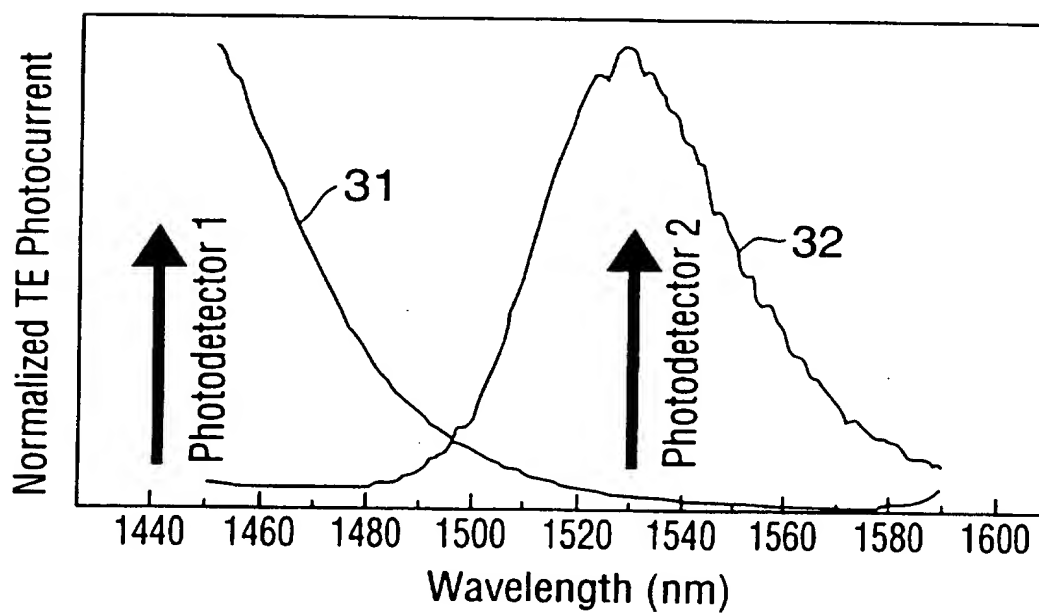
24. A precursor as claimed in claim 21 or 22, characterized in that said mask is an SiO<sub>2</sub> mask.
25. A semiconductor heterostructure having tuned bandgap made by a method as claimed in any of claims 1 to 8.
- 5 26. A super-luminescent diode characterized in that it includes a semiconductor heterostructure having tuned bandgap made by a method as claimed in any of claims 1 to 8.
- 10 27. A demultiplexer for wavelength division multiplexing characterized in that it includes a semiconductor heterostructure having tuned bandgap made by a method as claimed in any of claims 1 to 8.
- 15 28. An integrated internal laser modulator characterized in that it includes a semiconductor heterostructure having tuned bandgap made by a method as claimed in any of claims 1 to 8.
- 20 29. A single mode waveguide laser characterized in that it includes a semiconductor heterostructure having tuned bandgap made by a method as claimed in any of claims 1 to 8.
30. A high-powered laser characterized in that it includes a semiconductor heterostructure having tuned bandgap made by a method as claimed in any of claims 1 to 8.

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**FIG. 2a****FIG. 2b**

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**FIG. 4****FIG. 5**

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## Multiple Thickness Mask [Contact Mask]

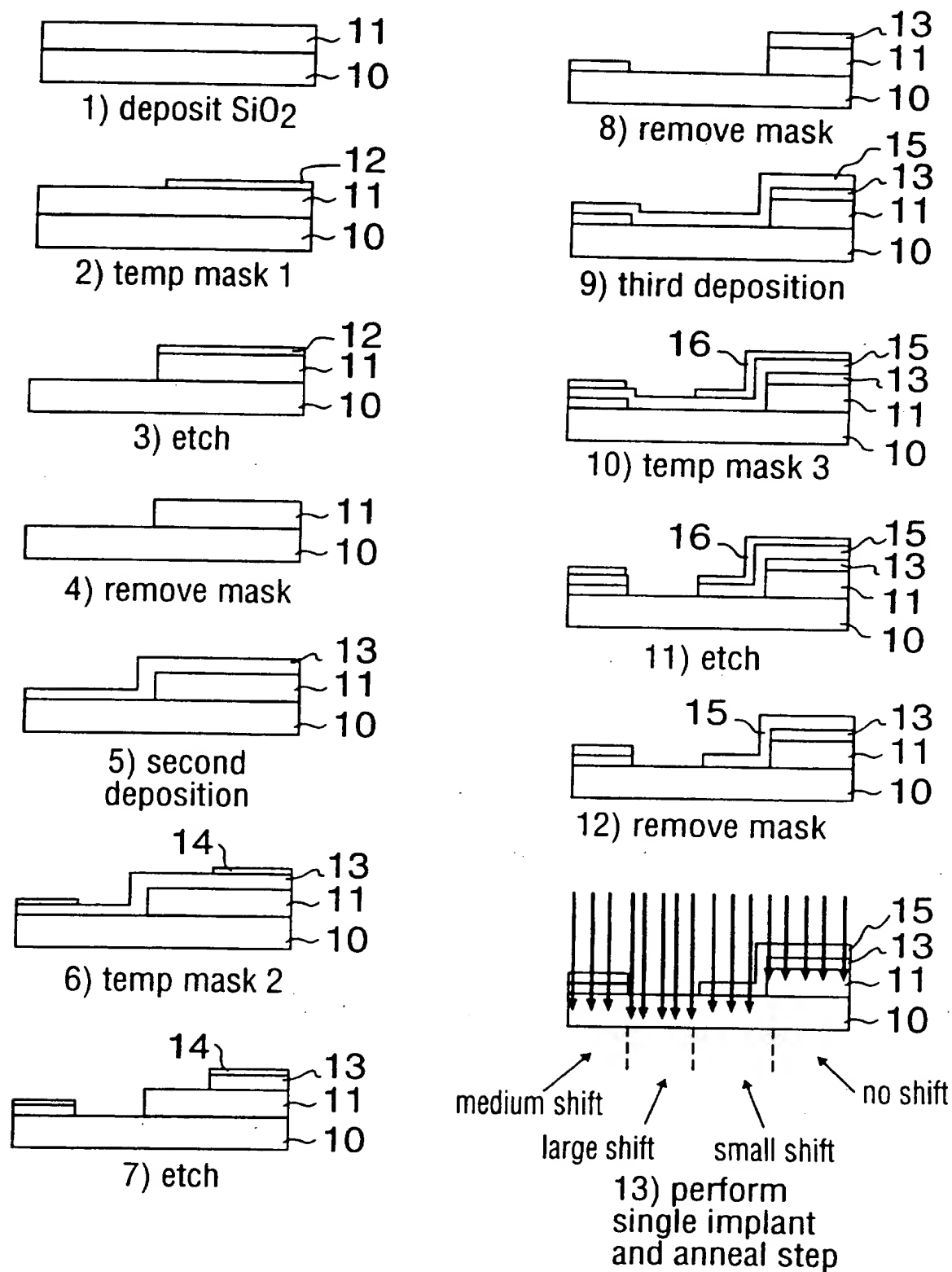
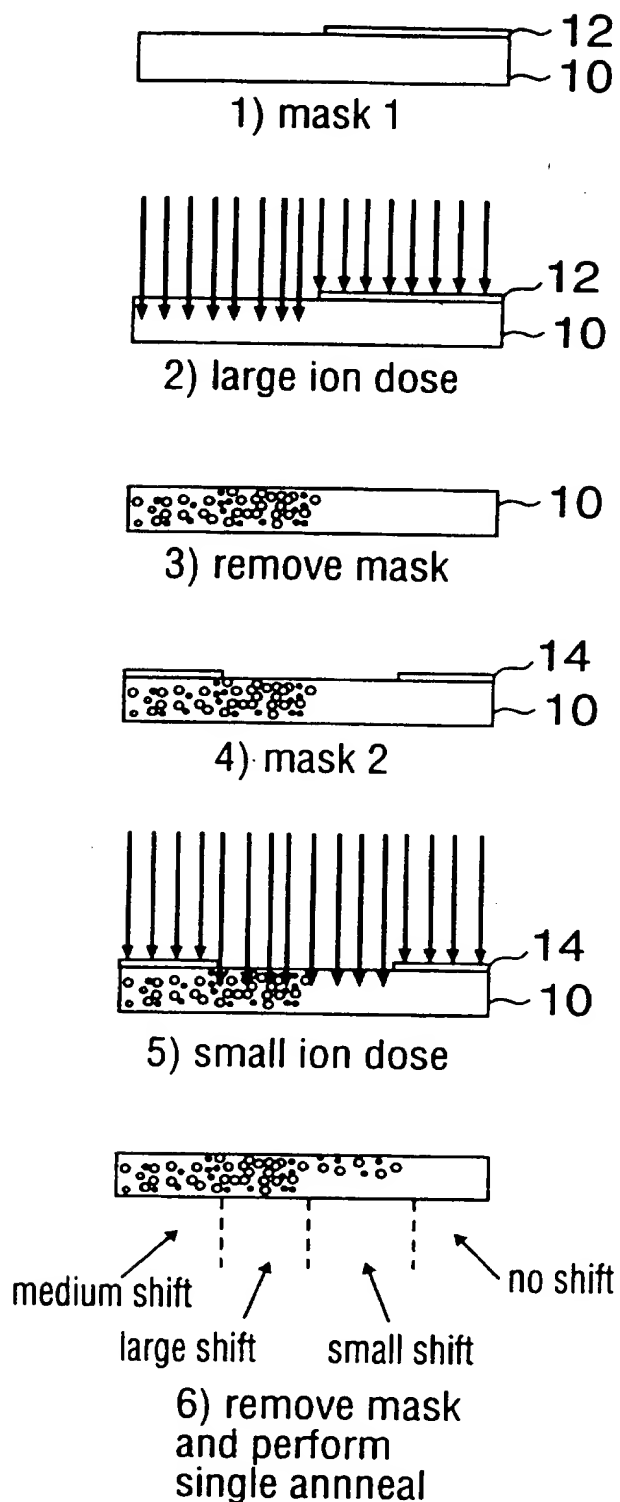


FIG. 7

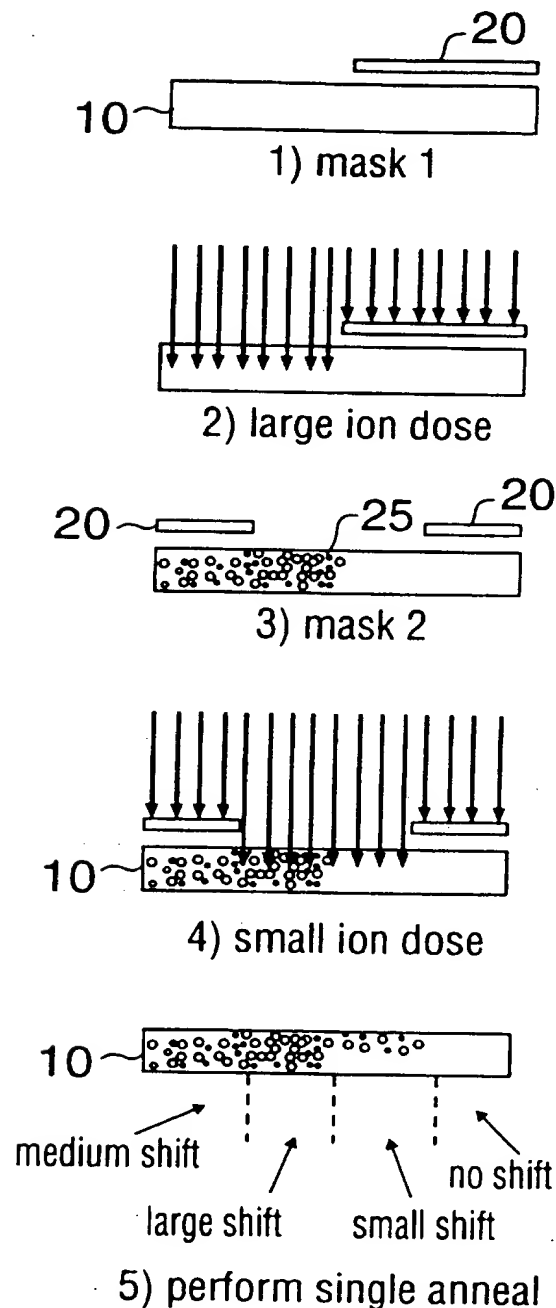
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### Multiple Implants (a) Contact Masks

**FIG. 9a**

### Multiple Implants (a) Contact Masks

**FIG. 9b**

# INTERNATIONAL SEARCH REPORT

International Application No

PCT/CA 96/00121

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
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